Scientific Motivation And Necessity of Cathode Development

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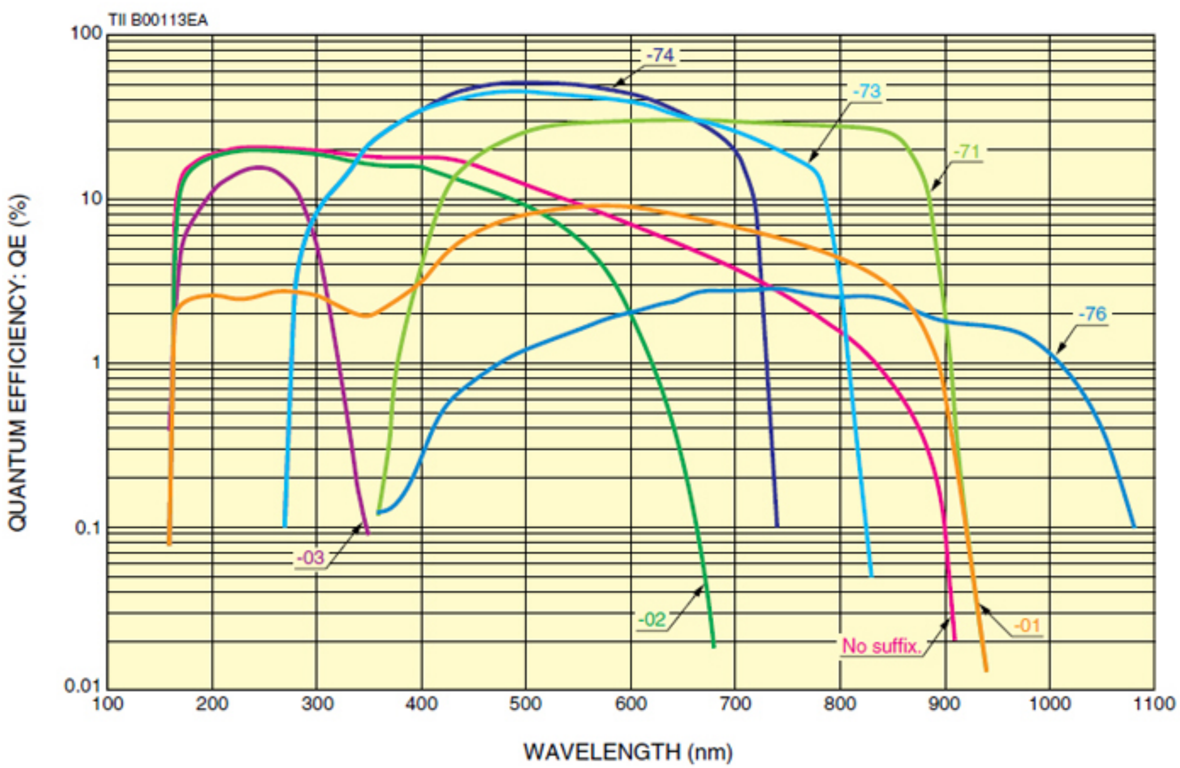
* Speakers of the review

The Photocathode Families

Hamamatsu: http://jp.hamamatsu.com/products/sensor-etd/pd014/index_en.html



Suffix	Photocathode	Input Window
-71	GaAs	Borosilicate Glass
-73	Enhanced Red GaAsP	Borosilicate Glass
-74	GaAsP	Borosilicate Glass
-76	InGaAs	Borosilicate Glass
Non	Multialkali	Synthetic Silica
-01	Enhanced Red Multialkali	Synthetic Silica
-02	Bialkali	Synthetic Silica
-03	Cs-Te	Synthetic Silica

- Required spectral response still not clear (main application)
- Future applications (combination with scintillators) will require response optimization

Why are we Planning a Large Cathode Effort?

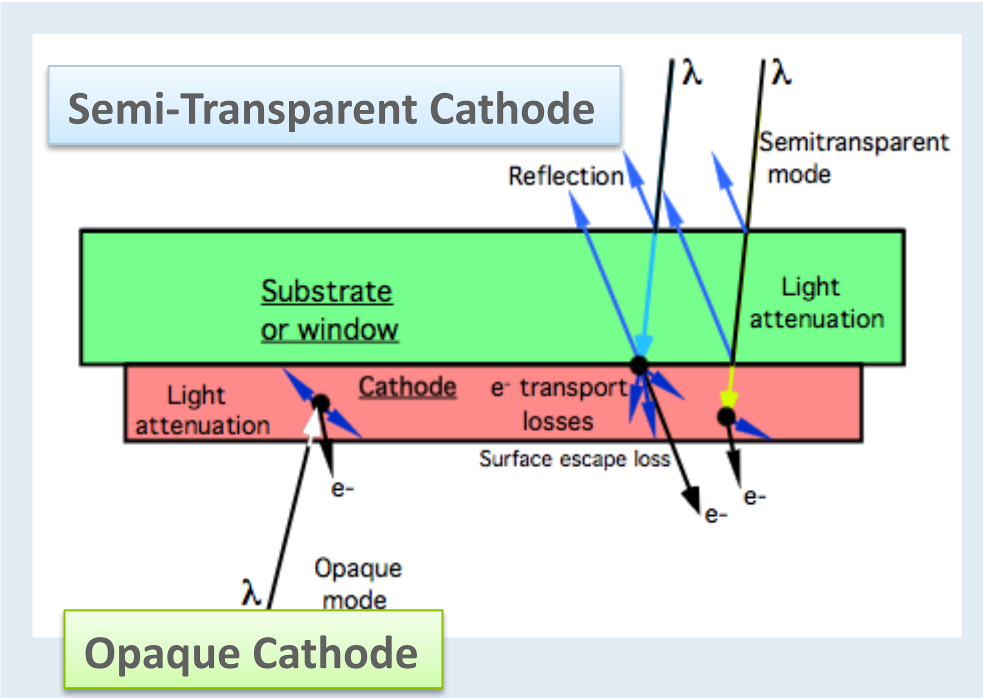
- **Multi-Alkali seems to have perfect cathode properties**
- But
  - Little understanding
  - Small community
  - No developed Industry
  - **Problems with mass-production**

- **Existing III-V cathode have not the right properties**
- But
  - Excellent understanding
  - Large community
  - Excellent developed Industry
  - Easy mass-production

	Property	Multi-Alkali	GaAs-based	GaN-based
Photocathode Properties	Wavelength response (typical)	150nm-500nm	450nm-850nm	100nm-350nm
	Typical efficiency	20%	20%	30-40%
	Maximum efficiency	50%	60%	80%
	Wavelength tunability	low	large	Very high
	Dark current	~100cps/cm2	~10000cps/cm2	~100cps/cm2
Growth properties	Single crystal substrate	no	yes	yes
	Easy scalable	No	yes	yes
	Large production volume possible	No	Yes	Yes
	Prefabrication possible	No	Yes	Yes
	Temperature sensitive	High	Medium	Medium
	Existing Industry	No (besides night vision / small area)	Yes (foundries available)	Yes (foundries available)
Basic Physics	Good understanding	No	Yes	Yes
	Microscopic understanding of growth	No	Yes	Yes
	2-D Fabrication tools	No	Yes	Yes
	3-D Fabrication tools	No	Yes	Some
	Theoretical description	No	Yes	Yes
	Band-structure engineering	No	Yes	Yes

Not Clear which will be the best for the project

What has to be Optimized?



The optimization Problem

- Optical Losses (ST-Cathode):
  - Entrance window
  - Interface window/cathode
  - Transmission losses (non absorbed photon)
- Optical Losses (Opaque-Cathode):
  - Vacuum-cathode surface
  - Transmission losses
- Electronic Losses:
  - Random walk results in maximal 50% efficiency
  - Recombination losses (highly correlated with defects)
  - Surface escape losses

The engineering Problem

- Cost efficient production
- Large variation in production volume
- Production compatibility with the full detection system

Detector properties

- Dark current
- Ion-bombardment (lifetime issues)
- Vacuum requirement of detection system
- In vacuum/inert gas assembly

The Challenges
Specifics to the Large Area Photo Detector Project:

- Extreme large production variation will require:
  - Fast production of individual components
  - Storage of individual subcomponents
  - Minimizing of production line “size” which can only be used for the detection system
  - Production cannot be done in piece-by-piece production
- Large area of detector:
  - Homogeneity requirements
  - Large facilities -> long production cycle (at least for piece-by-piece production)
  - Production yield problems?
  - Unusual shape (square) require specific tooling for usage of industrial instrumentation
- Low dark current:

The Challenges:
The Cathode and the Rest of the Detector

- Photocathode is the most sensitive part of the detector: None of the following properties can be changed after activation (without loss of QE)
  - Surface morphology
  - Chemical composition of surface & bulk
  - Structural composition of surface & bulk

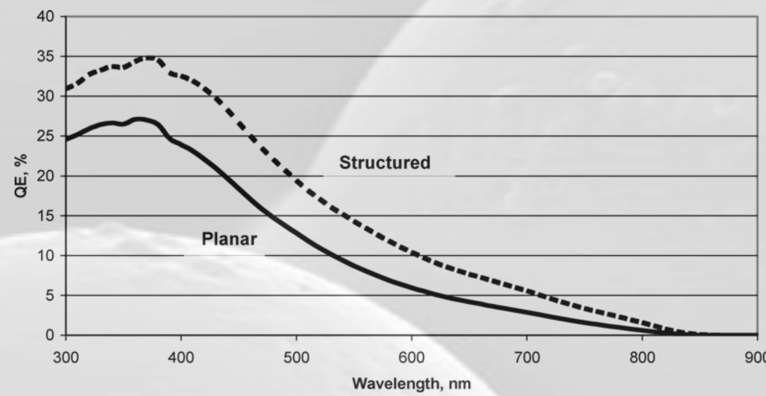
- Strong requirements on assembly and sealing technology
  - Maximal temperature and time in which the cathode is exposed to heat
  - Surface contamination due to degassing during the sealing process
  - Vacuum/inert gas requirements determine cost of the production

Research has to focus not only on high QE and low dark current but also on production related problems

The Approach

- The three different aspects:
  - Basic physics, growth aspects, optics: small size sample (10x10mm2)
  - Full functionality system test: 33mm diameter
  - 8”x8” issues: full size cathode
- Required infrastructure:
  - “Small” chamber size compatible with “lab” –size standard characterization
    - Cost efficient use of substrates
    - Cost efficient chamber design (cryostats/transfer systems)
    - Fast turnover (pumping down….)
    - Large throughput for characterization
    - System can produce also the 33mm diameter system with limited characterization option
  - Large flexible chamber
    - Minimum characterization
    - Ex-situ characterization
    - Development of evaporators, heaters…… (engineering problems)
  - Minimizing efforts on infrastructure
    - Using external collaboration partners

The Challenges: The Multi-Alkali



The Advantages:

- Perfect frequency response
- Very low dark current properties
- Moderate QE is standard (~20%)
- Recipes are available for small area & relative “low production volume”

The Challenges:

- Potentially much higher QE possible (up to 60%)
- Most optimization was achieved by optimizing window/cathode interface (optical and electronic influence)
- Alkali evaporation is an equilibrium problem (adsorption/desorption) making controlled coating technologies very difficult
- Significant engineering effort (constant temperature of cathode) is necessary to scale up to large size and high production volume
- High sensitivity of cathode to gases and temperature makes the sealing more challenging

The Challenges:
The III-V Materials (GaN and GaAs Based)

The Advantages:

- Well developed industry with scalable production facilities
- Excellent basic understanding of growth
- Good QE is demonstrated
- Very inert and stable cathode; can be partially fabricated and stored

The Problems:

- Light response has to be tuned to the wanted spectral range
- Dark current has to be suppressed (GaAs)
- Cost efficient transfer technologies or growth on glassy substrate have to be developed
- Increasing QE up to 60% and higher can be achieved by optimizing doping profiles

The Challenges:
Novel Concepts (Nano Structures and Alternative Processing)

The Advantages:

- Minimizing reflection losses
- Large tunability of materials (band-structure, mechanical properties)
- “natural” protection mechanism against ion-etching
- Conceptual new ways of electron emission enhancement (electric field enhanced)

The Problems:

- Unknown dark current behavior
- Novel technology with limited experiences and industrial facilities
- Many basic and fundamental aspects have to be understood before an industrial production is possible

http://cqd.eecs.northwestern.edu/research/ebeam.php

Summary

Status Quo:

- Small numbers of large area photocathode production with sufficient QE was demonstrated (curved surface)
- No 8”x8” flat system was demonstrated
- Currently there is no process available which allows to produce large amounts of these cathodes.

Our Program:

- Rational design or discovery of novel materials guided by basic understanding of functionality: Cross correlating microscopic properties and functionality
- The activities in ANL should be correlated with the requirements of industrial production
- The suggested program includes three areas of activities:
  - Multialkali PC
  - III-V PC (GaAs and GaN)
  - Nano-structured materials